Deep Convective Clouds and Chemistry (DC3)*

- Field campaign to study the impact of midlatitude deep convection on the upper troposphere-lower stratosphere (UT-LS) composition and chemistry above the continental United States (U.S.)
  - characterizing convective transports of chemical emissions and water to the UT-LS within the first few hours of active convection, investigating storm dynamics and physics, lightning and its production of nitrogen oxides.
- DC3 makes use of instrumented aircraft to characterize the composition and chemistry of storm outflow (NCAR Gulfstream-V) and inflow (NASA DC-8) regions ***simultaneously observed by ground-based radar and total lightning networks.***
- Observations are conducted at three strategic locations across the central (Colorado, Oklahoma) and southeastern (Alabama) U.S. to study different types of storms, forming in different environments, producing a variety of lightning types and thereby impacting the UT-LS and climate in different ways.

* DC3 scientific program overview (SPO; Barth et al. 2009a) and experimental design overview (EDO; Barth et al. 2009b): http://utls.tiimes.ucar.edu/science/dc3.html

NSF Proposal for

AN OBSERVATIONAL STUDY OF THE KINEMATIC AND MICROPHYSICAL CONTROL OF LIGHTNING PROPERTIES OVER ALABAMA DURING DC3

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Walt Petersen, Rich Blakeslee, Bill Koshak (NASA MSFC, unfunded Co-I's)

1. Deploy and operate a ground-based Doppler polarimetric radar network, total LMA, and mobile sounding unit and provide necessary convective weather forecasting and operations support during aircraft missions over northern Alabama during the intensive DC3 field campaign from May-June 2012.
2. Produce quality controlled preliminary and final data sets from the aforementioned ground-based observations over Alabama in support of core DC3 science objectives.
3. Conduct scientific analysis of DC3 ground-based radar, lightning and sounding data for the purpose of studying the kinematic, microphysical and environmental control of lightning properties, including type (intracloud [IC] versus cloud-to-ground [CG]), three-dimensional structure, and frequency.

Table 1. Summary of DC3 hypothesis categories and their relation to ground-based platforms and associated observations and analysis products.

Hypothesis Category	*Platforms*	*Required Observation/Analysis Types*
1) Lightning and its production of nitrogen oxides. (These hypotheses are the focus of this proposal and are discussed in Section 3.)	LMA	Flash rate, lightning channel lengths, lightning type, lightning location
	Radars	Multi-Doppler synthesized flow field, polarimetric hydrometeor identification, storm structure
	Sounding	Moisture, stability, shear parameters
2) Convective transport of air, water and chemical constituents	Radars	Multi-Doppler synthesized flow field including vertical motions, storm structure
	Soundings	Moisture, stability, shear parameters
3) Cloud hydrometeor effects on wet scavenging	Radars	Storm structure
	Soundings	Moisture, stability, shear parameters
4) Chemistry in the anvil	LMA	Lightning location and frequency
	Radars	Anvil structure and multi-Doppler synthesized flow field

DC3 Lightning-Convection-NO_x Related Hypotheses

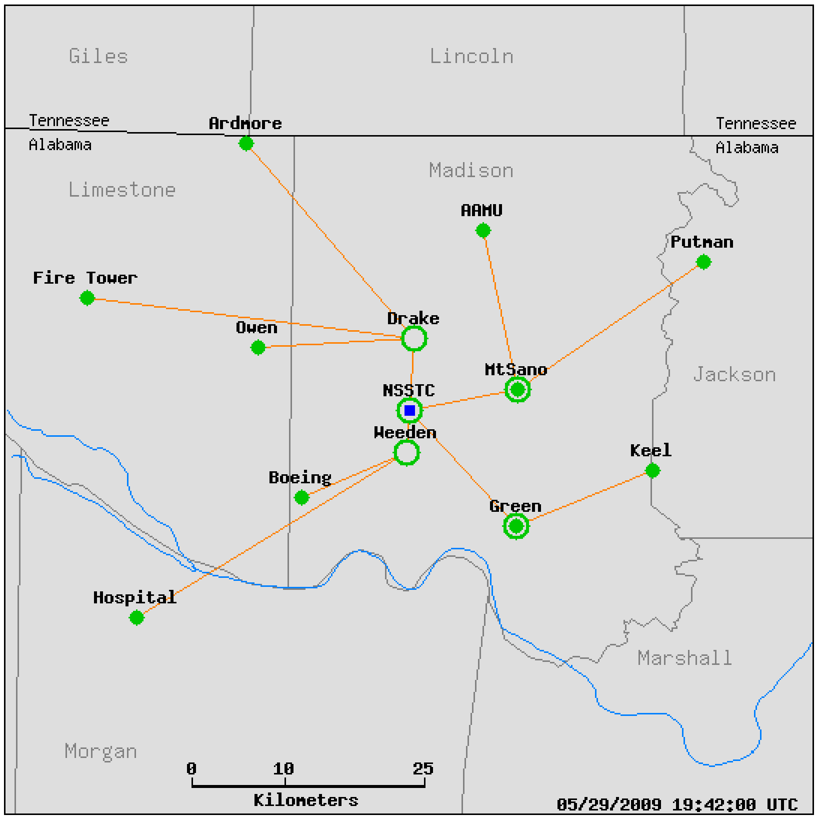
1. ***Hypothesis 1:*** *The contribution of lightning to NO_x concentration in the anvil, and subsequently in the upper troposphere, depends on overall flash rates and aggregate channel lengths at heights extending from just above the melting level to the uppermost region of the convective core. The amount of NO_x produced by a cloud-to-ground (CG) flash is on average roughly equivalent to that produced by an intracloud (IC) flash.*
2. ***Hypothesis 2:*** *The flash rates of a storm are proportional to the volume of updrafts greater than 10 m s^{-1} in the -10˚C to -40˚C layer and to storm graupel echo volume. CG lightning occurrence usually follows the occurrence of precipitation in the 0˚C to -10˚C layer after graupel has appeared in this region or higher regions. Conversely, cloud-to-ground lightning is inhibited in storms that produce little precipitation.*
3. ***Hypothesis 3:*** *Storms that produce inverted-polarity IC flashes in the upper part of storms and inverted-polarity CG flashes are those in which a large fraction of the adiabatic liquid water profile is realized as cloud liquid in the mixed phase region.*

DC3 scientific program overview (SPO; Barth et al. 2009
http://utls.tiimes.ucar.edu/science/dc3.html

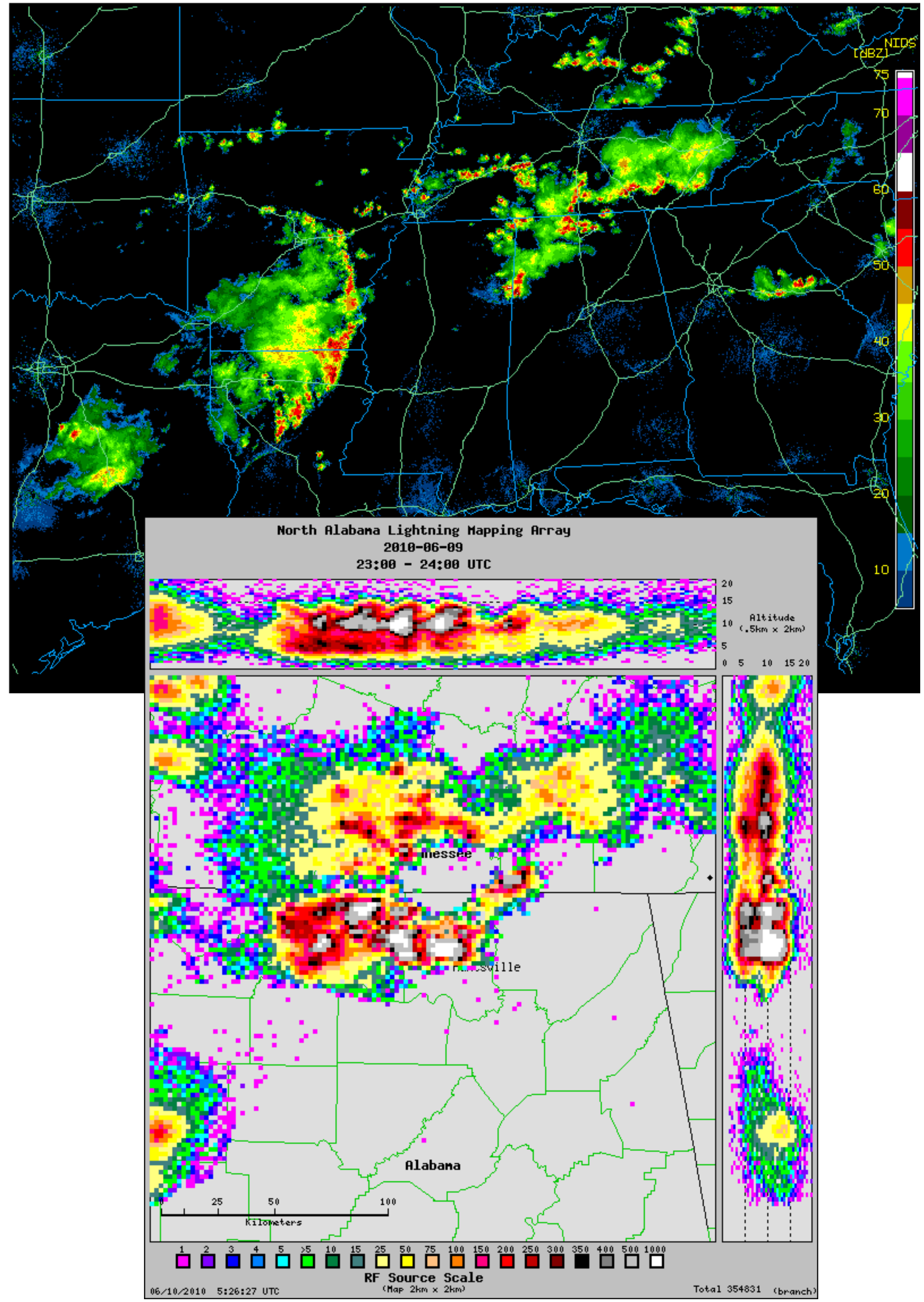
NASA MSFC Northern Alabama Lightning Mapping Array (NALMA)

- Based on original NMT LMA design.
- 10-11 VHF sensors
- Channel 5, 76-82 MHz
- Operating continuously since November 2001
- Goodman et al. (2005)

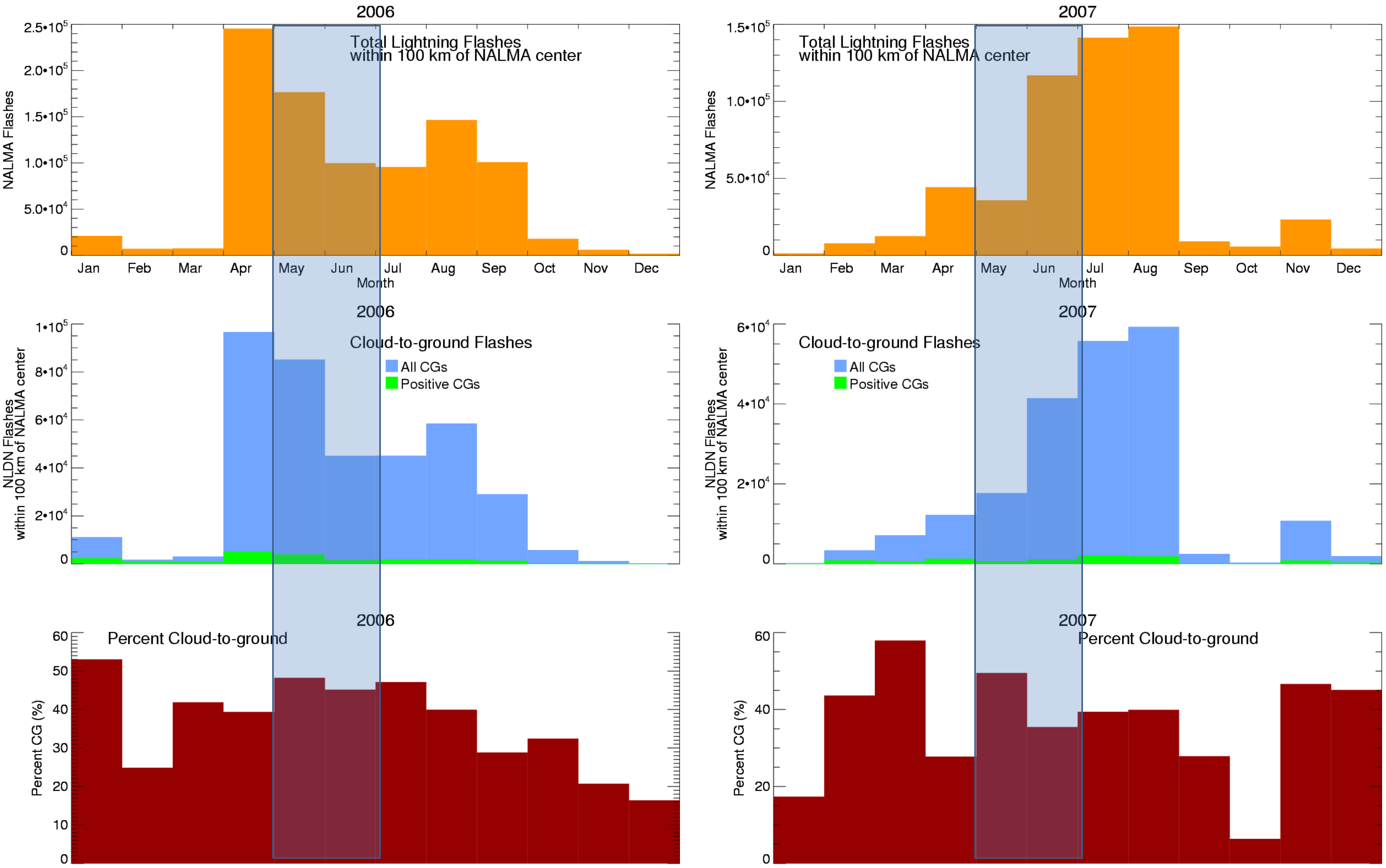
NALMA Sensor Locations



http://branch.nsstc.nasa.gov/PUBLIC/NALMA/



NALMA and NLDN Monthly Lightning Statistics for Northern Alabama



Courtesy: Dennis Buechler (UAHuntsville)

Table 2. **Cloud-to-Ground (CG) Fraction* and +CG % lightning statistics** associated with severe storm events during the proposed DC3 IOP period (15 May – 30 June) within 200 km of the three field experiment sites (1) ARMOR - Huntsville, Alabama, 2) CSU-CHILL – Greeley, Colorado and 3) Norman, Oklahoma) from analysis of combined Vaisala NLDN and NASA OTD data sets from 1995 to 1999.

Location	*Mean Severe Event CG Fraction* (%)*	*% of Severe Events with < 10% CG Fraction*	*Mean Severe Event +CG%*	*% of Severe Events with > 50% +CG*	*Number of Severe Events*
Alabama	34%	17%	3%	0% (none)	58
Colorado	18%	55%	50%	41%	49
Oklahoma	36%	15%	14%	8%	65

*CG Fraction= (CG Lightning Flash Rate) / (Total Lightning Flash Rate) = (NLDN) / (OTD - NLDN) where flash rates have been detection efficiency corrected.

Table 3. CG lightning **flash day** statistics over Huntsville, Alabama. The number of days per month with ≥ 1 (10) CG flashes day^{-1} within 100 km of the ARMOR radar in Northern Alabama based on an analysis of 2002 – 2010 NLDN CG lightning data.

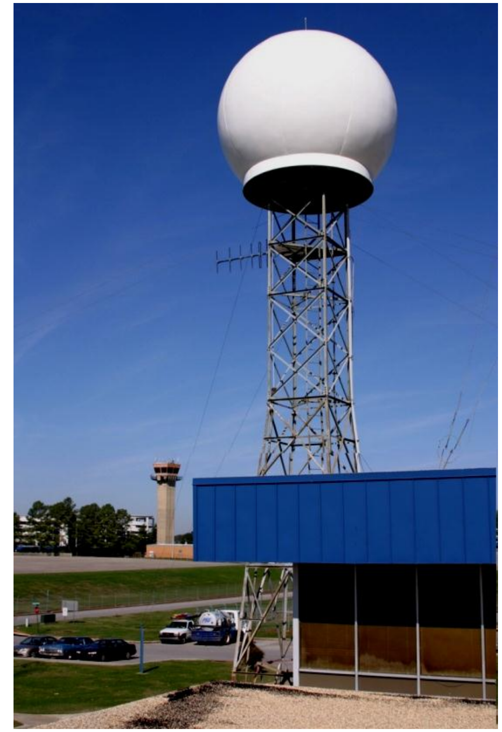
Northern Alabama Flash Day Statistics Minimum of 1 (10) flashes day^{-1} within 100 km of ARMOR				
	Mean	*Minimum*	*Maximum*	*Std Dev*
May	17.1 (15.3)	8 (7)	23 (22)	5.4 (4.6)
June	20.4 (19.2)	18 (15)	26 (23)	2.5 (2.7)

UAHuntsville/NSSTC Polarimetric-Doppler Radars

Mobile Alabama X-band (MAX) Radar

http://vortex.nsstc.uah.edu/mips/max/

Advanced Radar for Meteorological and Operational Research (ARMOR)

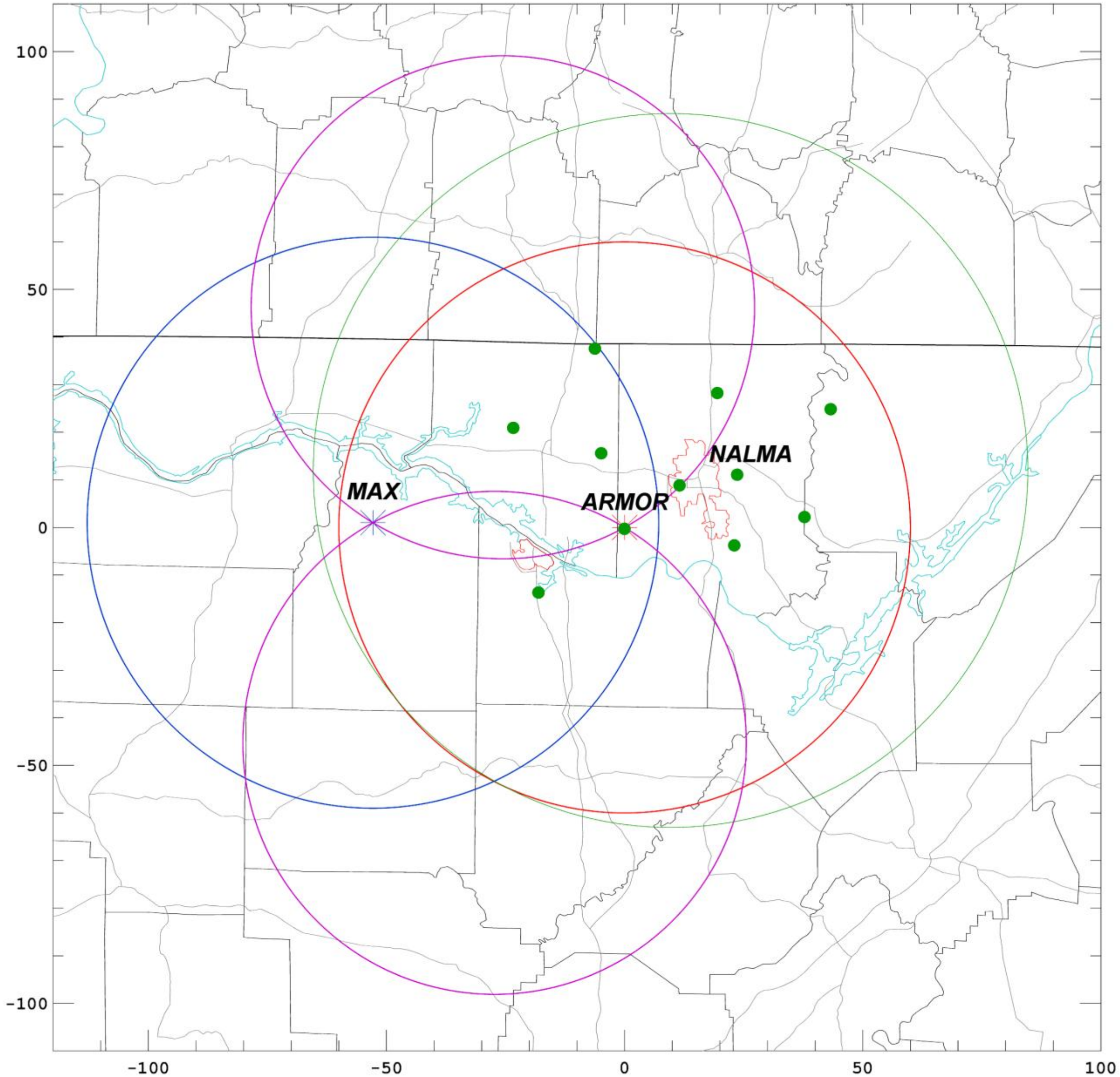


http://www.nsstc.uah.edu/ARMOR/

Table 4. NSSTC (UAHuntsville and NASA MSFC) radar specifications.

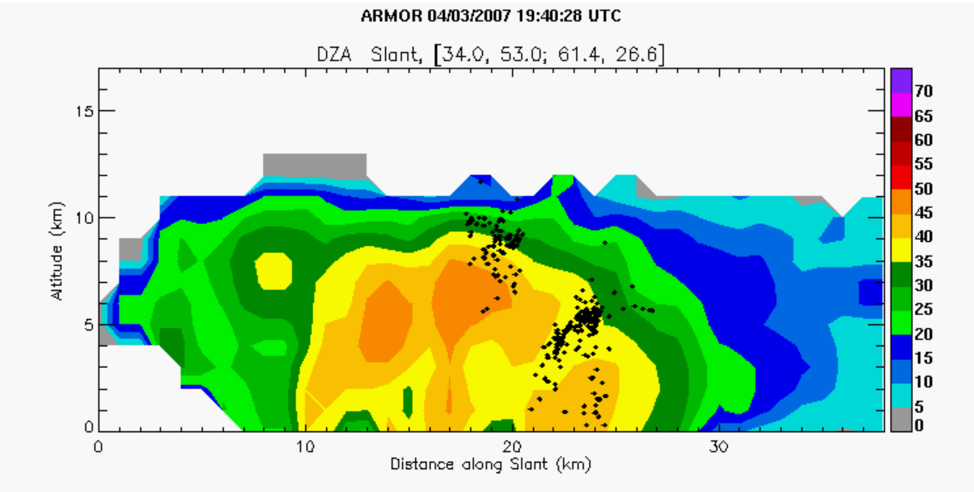
Radar Characteristic	**ARMOR (C-band)**	**MAX (X-band)**
Location	Huntsville Intl. Airport	Mobile (truck-based)
Transmit frequency	5625 MHz (magnetron)	9450 MHz (magnetron)
Peak Power	350 kW	250 kW
Pulse width	0.4, 0.8, 1.0, 2.0 μs	0.4, 0.8, 1.0, 2.0 ms
PRF Range	250-2000 Hz	250-2000 Hz
Antenna diameter/beamwidth	3.7 m (CF parabolic)/ 1.0°	2.44 m (CF parabolic)/0.95°
First side-lobe	-28 dB	-31 dB
Transmit polarization mode	1. STAR (H+V) or 2. H	1. STAR (H+V) or 2. H
Receive polarization	H and V	H and V
Signal Processor, Controller	VAISALA-SIGMET RVP/8, RCP/8	VAISALA-SIGMET RVP/8, RCP/8
Variables (depends on transmit mode 1 or 2)	1. Z_h, V_r, W, Z_{dr}, Φ_{dp}/K_{dp}, ρ_{HV} or 2. Z_h, V_r, W, LDR	1. Z_h, V_r, W, Z_{dr}, Φ_{dp}/K_{dp}, ρ_{HV} or 2. Z_h, V_r, W, LDR

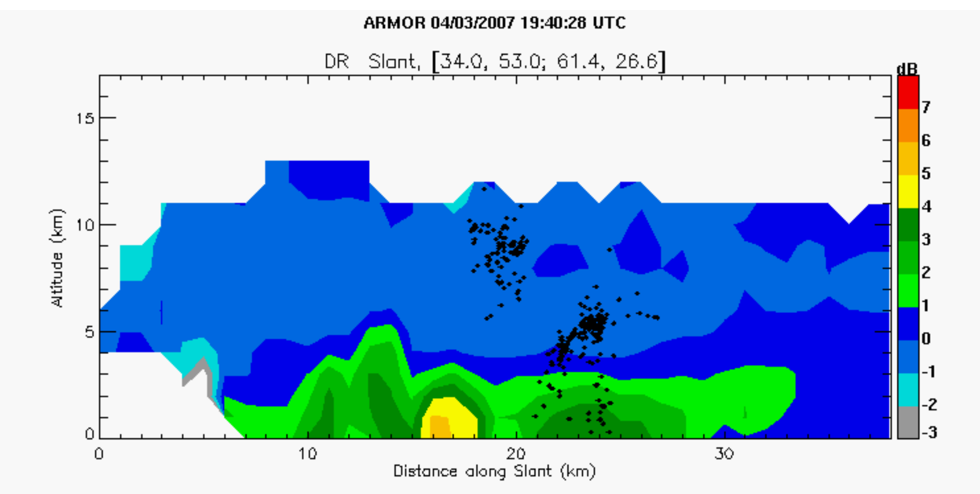
MAX Courtland Site
Dual-Doppler with ARMOR-MAX (or ARMOR-KHTX)

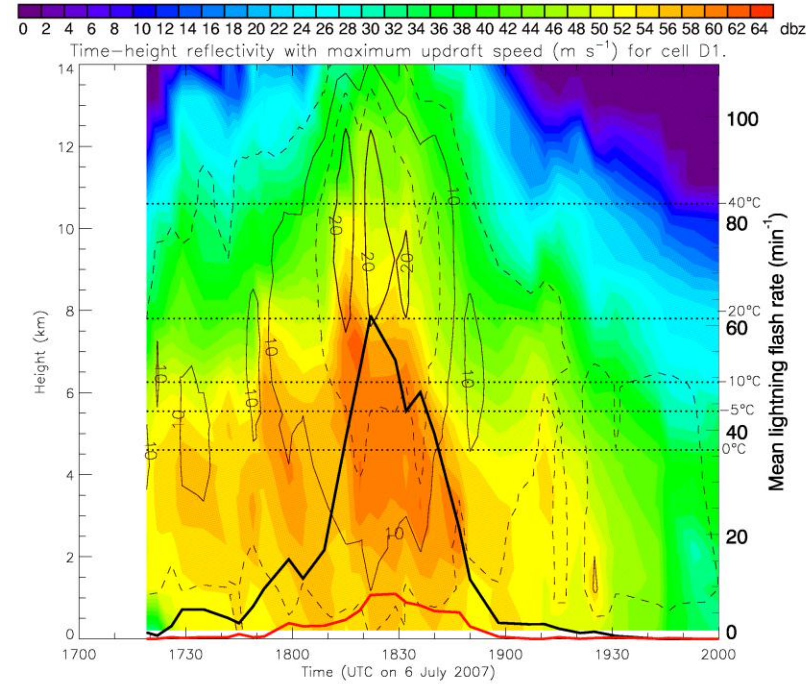


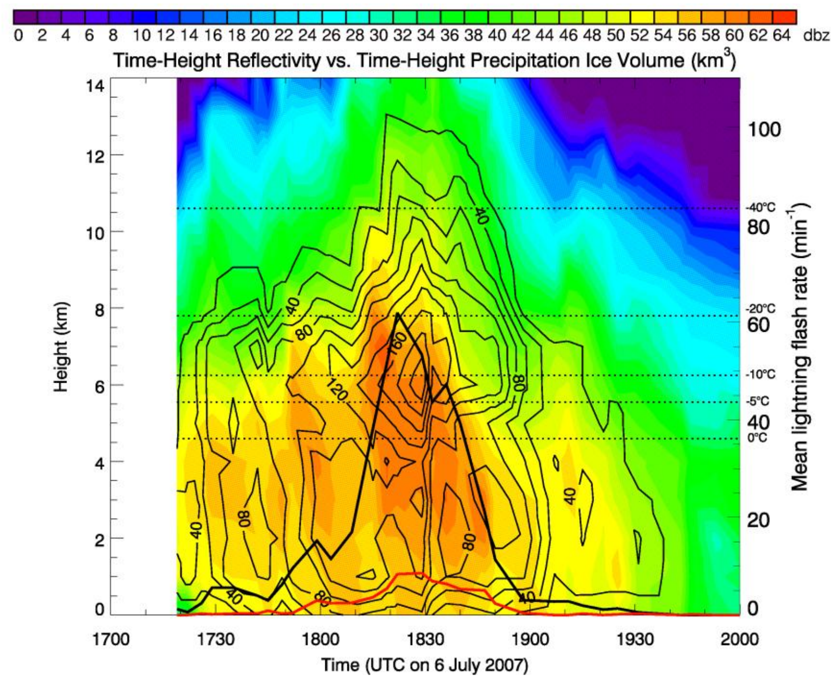
MAX allows flexible multi-Doppler radar convective-scale baseline strategy in and around LMA using pre-scouted sites.

LMA total lightning flash temporal and spatial behavior as a function of radar inferred storm kinematics and microphysics.







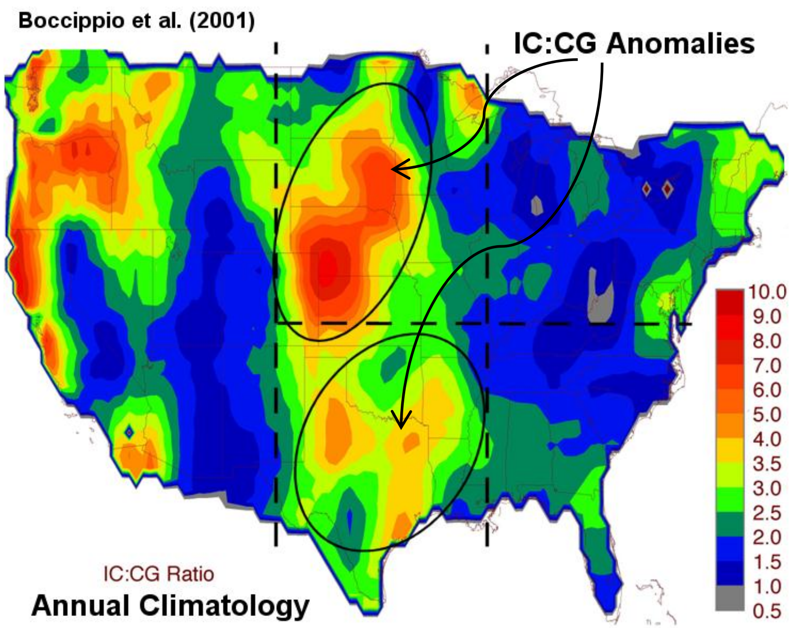


Courtesy: Elise Schultz (UAHuntsville)

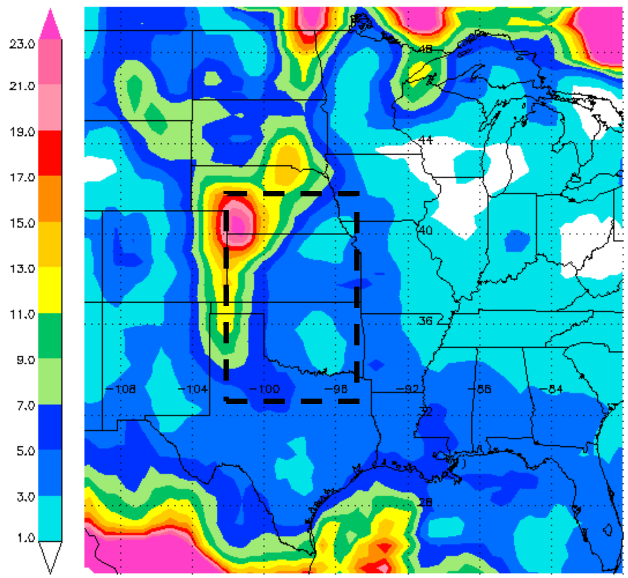
DC3 Alabama Outcomes

- Development of three-dimensional multi-Doppler radar synthesized flow fields, polarimetric radar inferred hydrometeor types and amounts, LMA inferred lightning properties and inflow proximity sounding data with a coincident suite of aircraft-based chemistry measurements in and around convection over Alabama.
- Characterize detailed lightning properties, including type (intracloud versus cloud-to-ground), three-dimensional flash structure, and flash rate and control of these lightning properties by updraft intensity, and precipitation type and volume as a function of convective lifecycle over northern Alabama.
- Document the environmental (instability, shear and moisture) control of storm morphology, dynamics, and physics, which in turn affect convective transport, lightning properties and hence generation of nitrogen oxides.

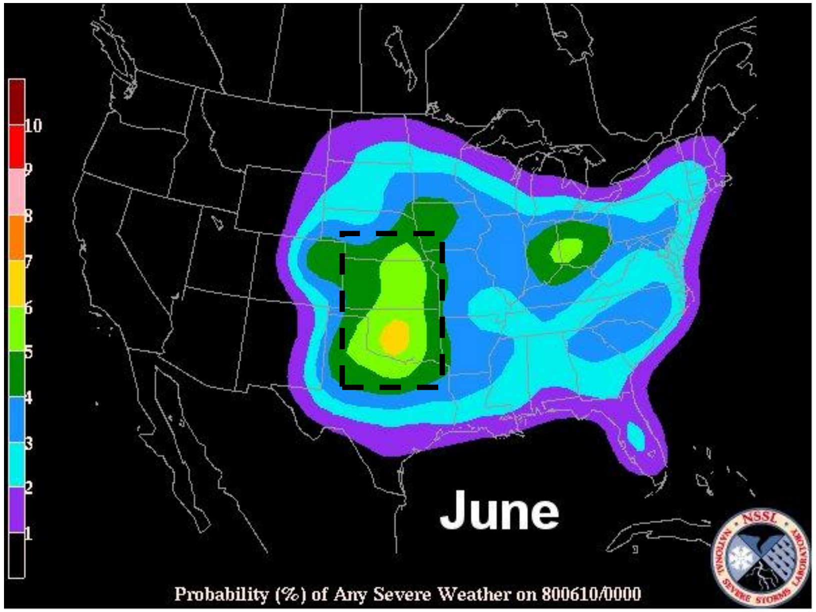
CONUS Climatology of Z=IC:CG



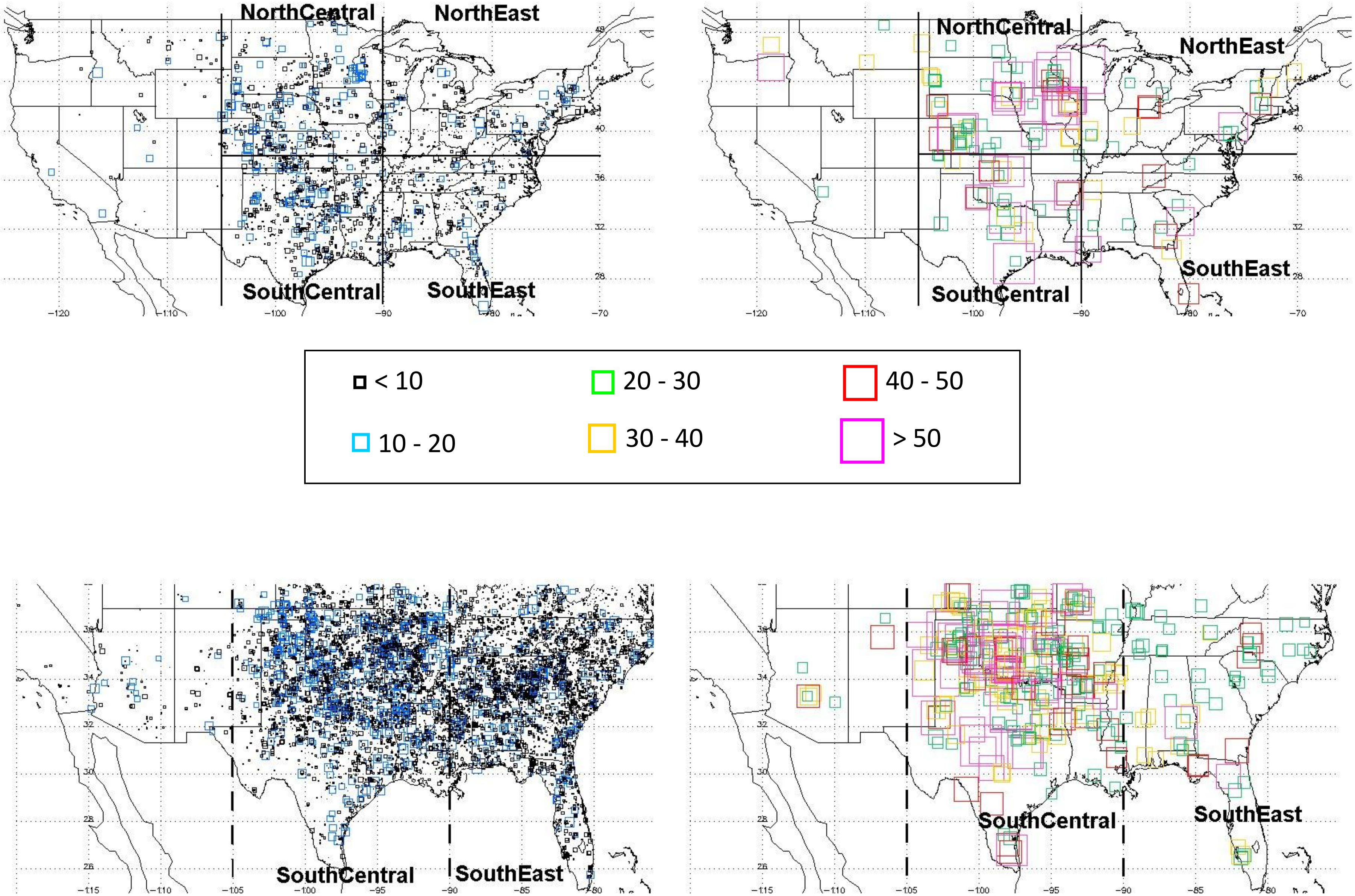
June IC:CG Climatology



June Severe Weather Probability

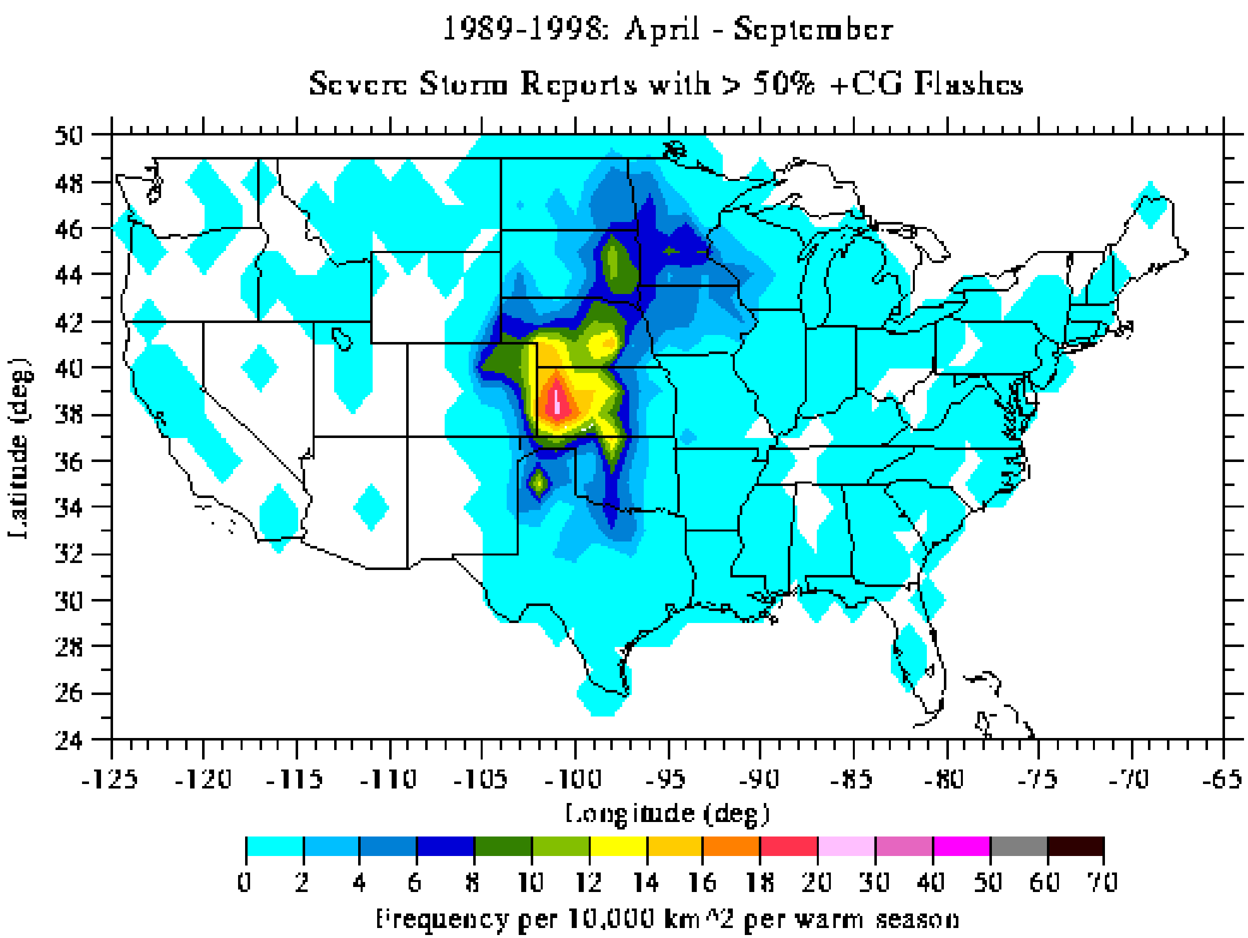


LIS/OTD-NLDN climatology of Z=IC:CG associated with individual severe weather events

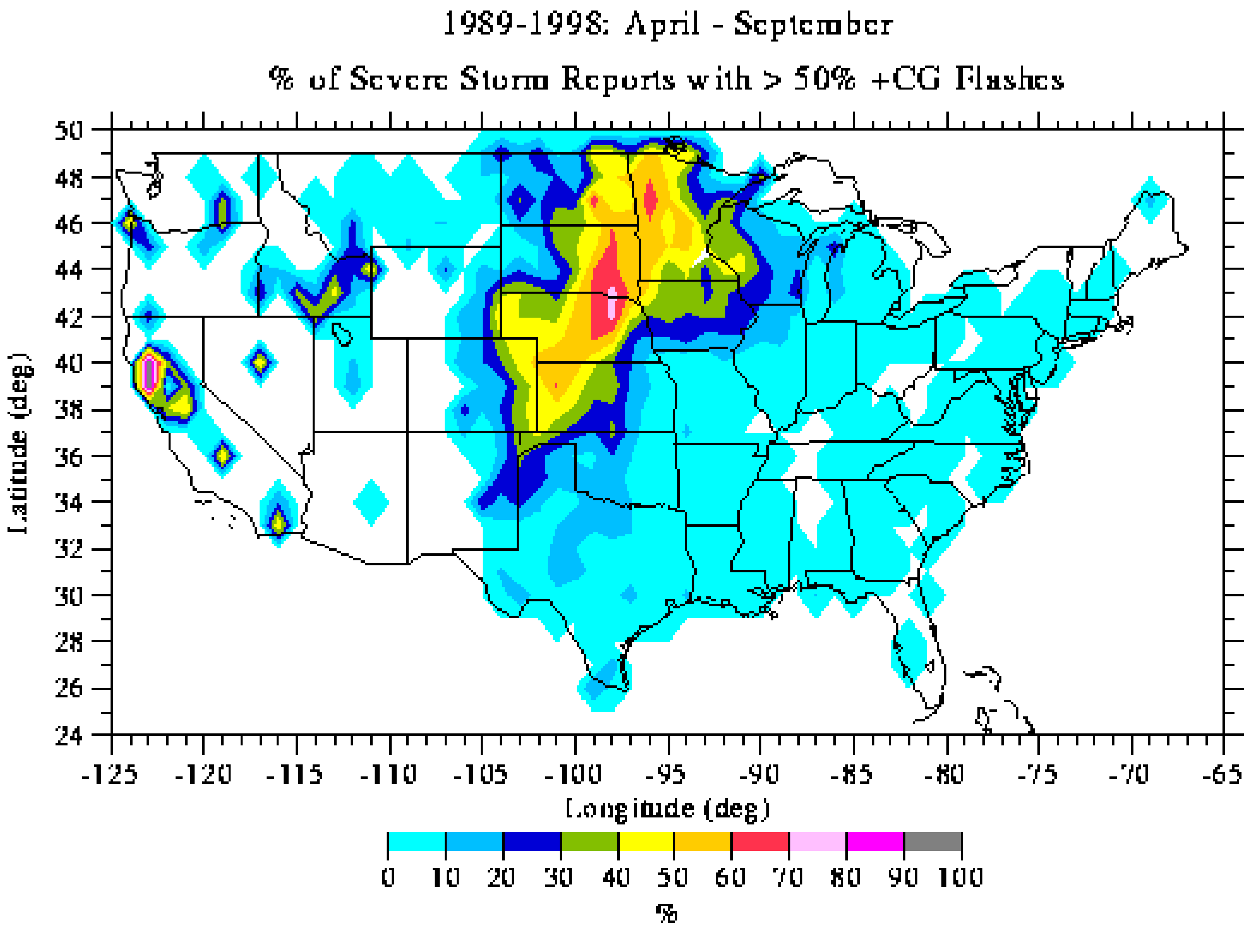


Region	**OTD**-based Mean Severe Event $Z = IC/CG = (OTD\text{-}NLDN)/NLDN$ 1995 – 1999, $I_p > 10kA$ (# Severe Events)	**LIS**-based Mean Severe Event $Z = IC/CG = (LIS\text{-}NLDN)/NLDN$ 1998 – 2007, $I_p > 10$ kA (# Severe Events)
CONUS (LIS: South)	4.6 (2765)	**4.8** (8913)
East	3.1 (1110)	*NA*
Southeast	2.9 (605)	**3.4** (4245)
Northeast	3.3 (505)	*NA*
Central	5.7 (1587)	*NA*
South-central	4.3 (904)	**6.1** (4537)
North-central	7.4 (683)	*NA*

Frequency of Severe Storm Reports Associated with >50% **Positive** CG Lightning



Percentage of Severe Storm Reports Associated with >50% **Positive** CG Lightning



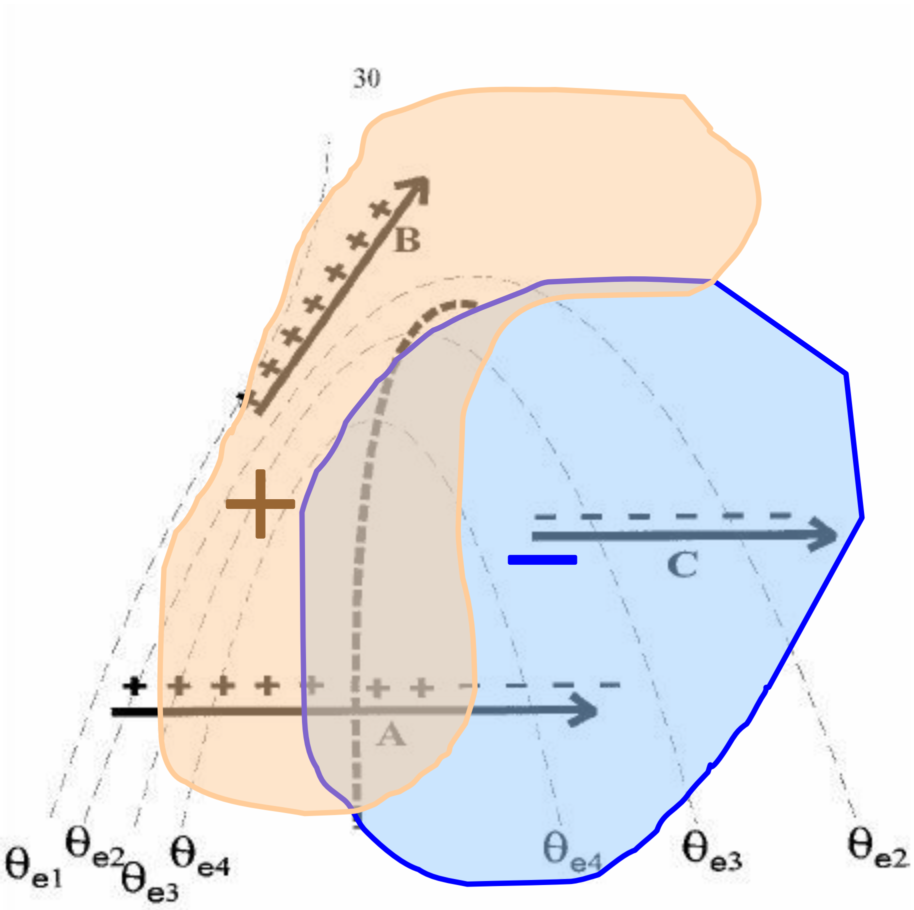
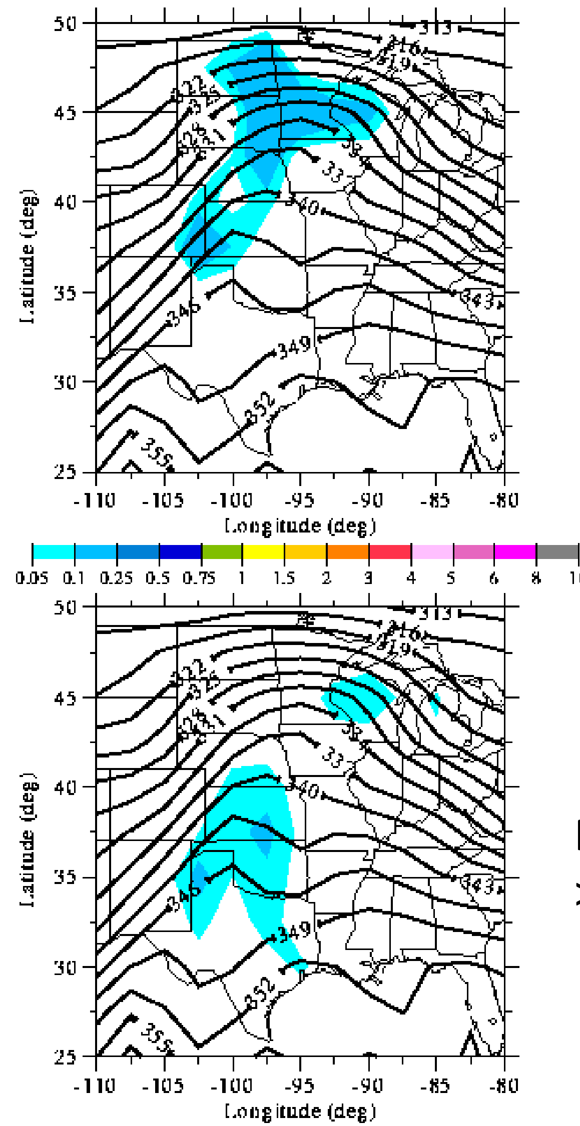


FIG. 9. Schematic diagram of conceptual model of CG lightning polarity as a function of location with respect to a surface θ_e ridge. Idealized storm tracks, with predominant CG lightning polarity indicated, are shown by bold arrows. Storm track A is for a reversal storm, B for a positive storm, and C for a negative storm. Thin dashed lines are contours of surface θ_e, where θ_{e4} is a local maximum. Thick dashed line is axis of the θ_e ridge. The length of storm track A is on the order of 100 km.

From Smith et al. (2000) with adaptations.

September, 1989-1998



PPCG

Frequency of >50 +CG

PNCG

Frequency of >90 -CG

Mean Monthly Near Surface Theta-E for Severe Outbreak Days (NCEP)